United States
Environmental Protection
Agency

Air Pollution Training Institute
MD 20
Environmental Research Center
Research Triangle Park, NC 27711

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Air

APTI
Course SI:431
Air Pollution Control Systems for Selected Industries

Self-instructional Guidebook

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Research Triangle Park, NC 27711

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The authors request that any material abstracted from this manual be appropriately referenced as a matter of professional courtesy in the following manner:

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Course Introduction

Description

This course is an introduction to the fundamental operating characteristics of particulate and gaseous pollutant emission control systems. It reviews physical, chemical, and engineering principles of control devices and the application of control systems to several industrial processes. Major topics include:

- Principles of gaseous emission control equipment, including absorbers, combustors, condensers, and adsorbers
- Principles of particulate emission control equipment, including cyclones, fabric filters, electrostatic precipitators, and scrubbers
- Application of control equipment to selected industries—power plants, municipal incinerators, asphalt batch plants, cement plants, acid plants, steel mills, petroleum refineries, kraft pulp mills, and smelters

Goal and Objectives

Goal

To familiarize you with the operation of air pollution control equipment and with nine industrial processes, their air pollution emission points, and equipment used to reduce their emissions.

Objectives

Upon completing this course, you should be able to:

1. describe the collection mechanisms used to capture particles and gases.
2. identify and describe the operation of four types of air pollution control devices used to reduce particulate emissions from industrial sources.
3. identify and describe the operation of four types of air pollution control devices used to reduce gaseous emissions from industrial sources.
4. name one air pollution control device used to collect both particles and gases emitted from industrial sources.
5. briefly describe the operation of industrial processes discussed in this course, such as acid plants, steel mills, and cement plants.
6. recognize the major air pollution emission points of these nine industrial processes.
7. describe air pollution control techniques for industrial sources presented in this course.

Requirements for Successful Completion

In order to receive 5.0 Continuing Education Units (CEUs) and a certificate of course completion, you must:

1. take a mail-in final examination.
2. achieve a final examination grade of at least 70%.

Materials

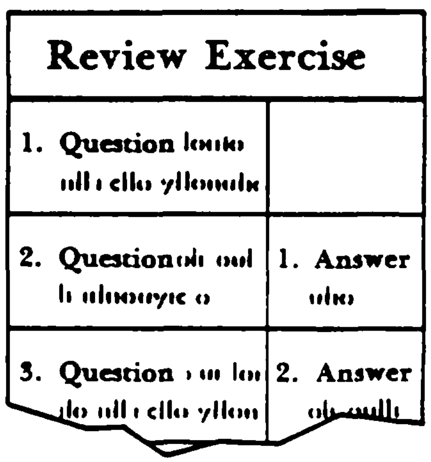
Reading

This guidebook—supplementary reading materials are not required.

Using the Guidebook

This book directs your progress through the course. The first eight lessons describe particulate and gaseous emission control equipment. The next nine lessons describe nine large industrial sources and the control equipment used to reduce emissions for each.

To complete a review exercise, place a piece of paper across the page covering the questions below the one you are answering. After answering the question, slide the paper down to uncover the next question. The answer for the first question will be given on the right side of the page separated by a line from the second question, as shown here. All answers to review questions will appear below and to the right of their respective questions. The answer will be numbered to match the question. **Please do not write in this book.** Complete each review exercise in the lessons. If you are unsure about a question or answer, review the material preceding the question. Then proceed to the next section.



Instructions for Completing the Final Examination

Contact the Air Pollution Training Institute if you have any questions about the course or when you are ready to receive a copy of the final examination.

After completing the final exam, return it and the answer sheet to the Air Pollution Training Institute. The final exam grade and course grade will be mailed to you.

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Lesson 1

Air Pollution Control

Lesson Goal and Objectives

Goal

To provide you with a brief history of air pollution control regulations and introduce some fundamental concepts underlying the use of control devices on industrial sources for both particulate matter and pollutant gases.

Objectives

At the end of this lesson, you should be able to:

1. recognize categories of Federal standards that specify air pollution emission limits for industrial sources.
2. recognize collection mechanisms in control devices for particulate matter.
3. recognize collection mechanisms in control devices for pollutant gases.
4. identify the three main parameters used for either judging the performance of or designing air pollution control equipment.

Overview

Industrial sources can emit a significant amount of particulate matter and pollutant gases into the atmosphere. In order to improve and protect the quality of the air, these emissions can be reduced by using different types of control devices.

Air cleaning devices have reduced particulate and gaseous pollutants from various industrial sources for many years. Originally, air pollution control equipment was used to control pollutants only if they were a nuisance, were highly toxic, or if they had some recovery value. Now, because of legislation such as the 1970 Clean Air Act and the 1977 Clean Air Act Amendments, more stringent control is required for many major industries.

The Federal government has set standards for pollutant levels in the ambient air. These standards, known as the National Ambient Air Quality Standards (NAAQS), are specified for pollutants such as sulfur dioxide (SO_2), carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2), particulate matter, and lead (Pb). In order that these ambient standards can be attained, industrial source emission standards have also been set. These source standards limit the pollutant concentration that can be emitted, and in some cases, specify the efficiency of the control equipment that must be installed on the source. Many new industrial sources are subject to regulations called New Source Performance Standards (NSPS). A new source is one that is contracted and installed at a facility after the date emission standards are proposed for that industry. New Source Performance Standards (NSPS) that have been promulgated are first published in the Federal Register and then in the U.S. Code of Federal Regulations. NSPS are set for a number of industrial source categories such as acid plants, cement plants, and fossil-fuel-fired steam generators. NSPS regulations specify emission limits and occasionally the type of control equipment that must be installed on various industrial sources.

In most cases, air pollution control equipment is installed on industrial sources to reduce emissions in order to meet regulations. However, it is possible to reduce emissions by other methods. Changing fuel sources, modifying or changing raw materials, or using alternative production procedures also can reduce emissions without adding on control equipment. These methods are usually considered before installing expensive control equipment.

Particulate Emission Control

Cyclones, baghouses, electrostatic precipitators and wet scrubbers are used to reduce particulate emissions from industrial sources. All of these devices collect particulate matter (particles) by mechanisms involving an applied force. The simplest collection force is *gravity*. Large particles moving slow enough in a gas stream can be overcome by gravity and be collected. Gravity is responsible for collecting particles in a simple device such as a settling chamber.

The settling chamber was one of the first devices used to control particulate emissions; however, it is very rarely used today. Because its effectiveness in collecting particles is very low, it cannot be used to meet most air pollution regulations. However, the settling chamber can be used as a precleaner for other particulate emission control devices—to remove very large particles. A typical settling chamber is presented in Figure 1-1. The unit is constructed as a long horizontal box with an inlet, chamber, outlet, and dust collection hoppers. The velocity of the particle-laden gas stream is reduced in the chamber. All particles in the gas stream are subject to the force of gravity. At the reduced gas velocity in the chamber, the large particles (greater than 40 μm in diameter) are overcome and fall into the hoppers.

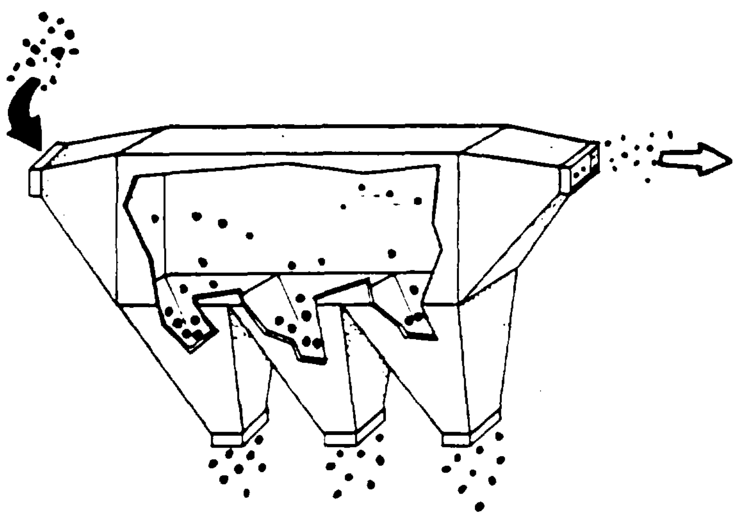

Figure 1-1. Gravity settling chamber.

Another collection force used for particle capture is *centrifugal force*. The shape or curvature of the collector causes the gas stream to rotate in a spiral motion. Larger particles move toward the outside of the wall by virtue of their momentum (Figure 1-2). The particles lose kinetic energy there and are separated from the gas stream. Particles are then overcome by gravitational force and collected. Centrifugal and gravitational forces are both responsible for particle collection in a cyclone.

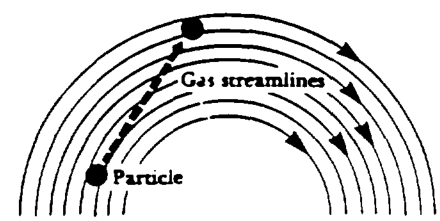

Figure 1-2. Centrifugal force.

In both fabric filters and wet collectors, three separate forces are responsible for particle collection: impaction, direct interception, and diffusion. In a fabric filter, the target object for particle capture is a stationary filter bed supported by the fabric. In a wet collector, the target object is a water droplet.

Consider the case of an individual fiber in a fabric filter. *Impaction* occurs when the particle is so large that it cannot follow the gas streamlines around the stationary impaction target. It hits or impacts on the fiber (Figure 1-3). *Direct interception* is a special case of the impaction mechanism. The center of a particle may follow the streamlines formed around the fibers. A collision will occur if the distance between the particle center and the collection surface is less than the particle radius (Figure 1-4). Particles below 0.1 μm in aerodynamic diameter undergo Brownian motion, randomly moving or diffusing throughout the gas volume. The mechanism of *diffusion* is responsible for the collection of particles which are so small that they become affected by collisions of molecules in the gas stream. The randomly moving particles then move or diffuse through the gas to impact on the fiber and are collected (Figure 1-5).

The other primary particle collection mechanism involves electrostatic forces. The particles can be naturally charged, or, as in most cases involving ***electrostatic attraction***, be charged by subjecting the particle to a strong electric field. The charged particles migrate to an oppositely charged collection surface (Figure 1-6). This is the collection mechanism responsible for particle capture in both electrostatic precipitators and charged droplet scrubbers. In an electrostatic precipitator, particle collection occurs because of electrostatic forces only. In a charged droplet scrubber, particle removal occurs by the combined effects of impaction, direct interception, diffusion, and electrostatic attraction. Particles are charged in these scrubbers to enhance both diffusion and direct interception.

Particle collection can occur from the combined effect of the mechanisms discussed. In addition, particles can agglomerate or grow in size through cooling or increasing humidity or from electrostatic effects. Agglomerated particles thus have a larger

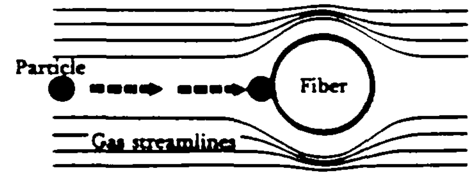

Figure 1-3. Impaction.

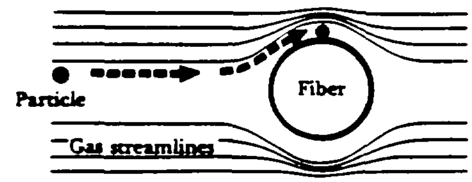

Figure 1-4. Direct interception.

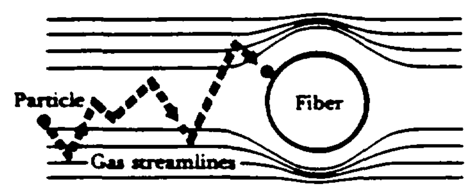

Figure 1-5. Diffusion.

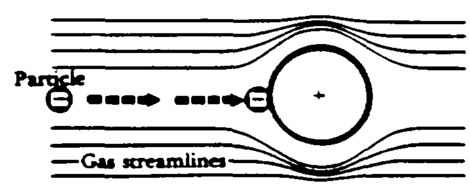

Figure 1-6. Electrostatic attraction.

aerodynamic diameter and can be collected by impaction, interception, or gravitational forces. Many factors influence the choice of a control device used to reduce industrial particulate emissions. If emitted material can be used or reused in the process, dry collection should be used. If the pollutant has little economic value, collection should be accomplished and the pollutant disposed of safely and economically. The industrial process and potential control devices must both be carefully reviewed. The conversion of an air pollution problem into a water pollution problem can create a more difficult disposal problem.

Gaseous Emission Control

Gaseous pollutants are emitted from a variety of industrial processes. Those frequently controlled include sulfur dioxide (SO_2), nitrogen oxides (NO_x), nonmethane organics (NMO) and carbon monoxide (CO).

Absorbers, adsorbers, combustors (incinerators), and condensers are used to control gaseous emissions. The use of a particular device depends on the physical and chemical properties of both the pollutant and the exhaust stream. More than one device may be able to control emissions from a given source. For example, vapors (gaseous emissions) generated from loading gasoline into tank trucks may be controlled by any of these devices. On the other hand, absorbers are most commonly used for reducing SO_2 emissions generated as a result of burning fossil fuels.

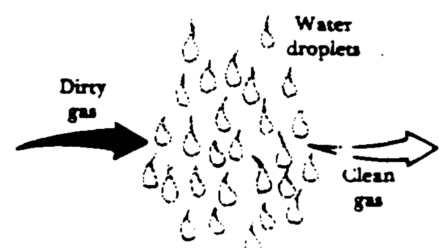

Figure 1-7. Absorption.

As with particle collection, gases are collected by various mechanisms. Gases can be removed by an operation called absorption—gases are dissolved in a liquid. A gaseous pollutant exhaust stream contacts and is dissolved by the liquid (Figure 1-7). The liquid used most often is water since it is inexpensive, readily available, and can dissolve a number of pollutants.

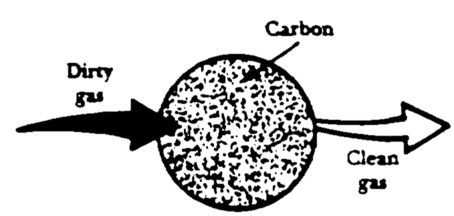

Figure 1-8. Adsorption.

Gases can also be removed by an operation called adsorption—gaseous pollutants adhere to a solid surface (Figure 1-8). Activated carbon is the solid most often used since many hydrocarbon vapors and odorous organic compounds from industrial exhaust streams adhere to the carbon.

Gaseous pollutants can also be controlled by burning a gaseous pollutant (organic) in a chamber to form harmless products—carbon dioxide and water. Auxiliary fuels are burned in the chamber in order to raise the pollutant's temperature to the point where it will readily oxidize. Natural gas and oil are commonly used as auxiliary fuels to incinerate gaseous pollutants.

Gaseous vapor can be condensed into liquid droplets. This is usually accomplished by reducing the temperature of the pollutant-laden gas stream until liquid droplets form. Condensers are used to remove water vapor and also condensible organic compounds from industrial exhaust streams.

General Concerns

Collection Efficiency

The performance of air pollution control equipment is often judged in terms of its collection efficiency. Collection efficiency is defined as the percentage reduction in pollutant concentration between the inlet and outlet of the control device; or

$$\text{Collection efficiency (by weight)} = \frac{\text{pollutant concentration at the inlet} - \text{pollutant concentration at the outlet}}{\text{pollutant concentration at the inlet}} \times 100\%$$

A high value for efficiency indicates that a greater degree of control is achieved on the source. A low value indicates that lesser control occurs with more pollutants emitted into the atmosphere.

Emission limits are usually set by existing air pollution regulations. The control to be achieved depends on the allowed outlet concentration and the quantity of emissions generated from the process. For example, assume that a source emits 1800 mg/m^3 particulate matter from its stack (uncontrolled). If the regulation states that the maximum allowable emission rate cannot exceed 90 mg/m^3, then the collection efficiency must be:

$$\text{Collection efficiency} = \frac{1800 - 90}{1800}$$

$$= 0.95 \text{ or } 95\%$$

In order to meet the regulations in this case, a control device having 95% collection efficiency must be installed on this source.

Air pollution control equipment is often designed specifically for the industrial source on which it is installed. Several design factors should be considered. One is the concentration or grain loading of particulate pollutants in the process exhaust stream. Pollutant concentration is typically expressed in terms of pounds per cubic foot (lb/ft^3), grains per cubic foot (gr/ft^3), and grams per cubic meter (g/m^3). For gaseous pollutants, concentration is expressed in terms of parts per million (ppm) by volume, e.g., $m^3/10^6m^3$, $ft^3/10^6ft^3$. Both the level and fluctuation of grain loading are very important. Some control devices, such as fabric filters, are relatively unaffected by high levels or great fluctuations in particle concentration. Others, such as electrostatic precipitators, generally do not function effectively with large fluctuating concentration levels. Another related problem can occur when the exhaust gas velocity changes rapidly. Some control devices are designated to operate at specific exhaust gas velocities. Large changes in gas velocities can drastically affect the unit's collection efficiency.

Particle Characterization

Particle characteristics such as size, shape, and density must be considered when designing control systems. Particulate matter is the finely divided solid or liquid material that exists as particles in the stack gas. Particle size is usually expressed in terms of the aerodynamic diameter. The aerodynamic diameter describes how the particle moves in a gas stream. Particle diameters are measured in units of micrometers (μm). Particles with large diameters ($> 10\ \mu m$) can be collected in cyclones. Particles having small diameters ($< 5\ \mu m$) must be collected in more sophisticated devices such as scrubbers, baghouses, or electrostatic precipitators. Thus, the collection efficiency of a specific control device depends on the size of the particles in the exhaust stream. Devices called impactors are commonly used to determine the particle size distribution of exhaust streams from industrial sources. The impactor is inserted into the stack and a sample stream is pulled into the impactor. Particles impact on collection or impaction plates according to their aerodynamic size. Additional information on particle size devices can be obtained from APTI Course 413 *Control of Particulate Emissions—Student Manual* EPA 450/2-80-066.

Pressure Drop

Another important characteristic of control devices is the effect they have on the flow of exhaust gas in an industrial process. A resistance to the flow of gas can build up, especially if the gas must be forced through small constrictions or openings. Pressure drop is a measure of the air resistance across a system. Pressure drop, also called gas pressure drop, describes the pressure loss between the inlet and outlet sections of the control device. Collectors with large pressure drops would require larger fans (and greater power requirements) to either push or pull the exhaust gas through the system. An increase in pressure drop means that there is a larger pressure loss in the system. Some control devices such as venturi scrubbers are designed to operate at high pressure drops [as great as 254 cm H_2O (100 in. H_2O)]. On the other hand, electrostatic precipitators are designed to operate at much lower pressure drops [usually less than 2.54 cm H_2O (1.0 in. H_2O)].

In order to reduce pollutant emissions from industrial processes, the control system should be designed to meet emission limitations at minimum cost with maximum reliability. The basic trade-offs involve decisions between collection efficiency, installation costs, and operating costs. This course will review the many control techniques which have been used to meet the requirements of air pollution regulations for various industrial sources.

Review Exercise

1. Maximum pollutant levels set by the Federal government for specific air pollutants in the ambient air are referred to as a. New Source Performance Standards. b. Special Source Emission Standards. c. National Clean Air Act Regulations. d. National Ambient Air Quality Standards.	
2. The NSPS regulations are designed to ensure that all new plants have a. the same minimum emission requirements. b. identical control devices. c. none of the above	1. d. National Ambient Air Quality Standards.
3. Impaction, direct interception, and diffusion can all be responsible for particle collection in a. fabric filters. b. adsorbers. c. condensers. d. incinerators.	2. a. the same minimum emission requirements.
4. All control devices used to collect particulate matter operate using a. electrostatic attraction. b. water. c. an applied force.	3. a. fabric filters.
5. In a simple control device such as the settling chamber, large particles moving slow enough in a gas stream can be overcome by a. centripetal force. b. gravity. c. centrifugal force. d. impaction.	4. c. an applied force.
	5. b. gravity.

6. How does centrifugal force cause particles to separate from the gas stream? What shape encourages this separation?	
7. If a particle is so large that it cannot follow the gas streamlines around a fiber or droplet, it will ________ the object. a. bypass b. diffuse through c. impact on d. electrically charge	6. The gas stream rotates in a spiral fashion. The particles' momentum causes them to break from the gas stream and hit the walls of the device. The device is usually in a curved or circular shape.
8. A high value of collection efficiency means that a. the source does not need a control device. b. a high percentage of the pollutant is collected. c. a high percentage of the pollutant is emitted.	7. c. impact on
9. If ________ is large or constantly fluctuating, some control devices may not function efficiently. a. particle concentration b. grain loading c. gas velocity d. all the above	8. b. a high percentage of the pollutant is collected.
10. Aerodynamic diameter describes how a particle moves in a gas stream. It has a direct bearing on a. the collection efficiency of a specific control device. b. the ability of the particle to be collected. c. both a and b	9. d. all the above
11. ________ is a measure of the resistance to gas movement through a control device. a. Collection efficiency b. Particle-to-particle density c. Pressure drop d. none of the above	10. c. both a and b
12. An increase in pressure drop means that the pressure loss in the system is larger/smaller.	11. c. Pressure drop
13. True or False? All control devices must operate at high pressure drops to be efficient.	12. larger
	13. False